LA-UR -80-2394

TITLE: FEL DEVELOPMENT PROGRAM AT LOS ALAMOS SCIENTIFIC LABORATORY

AUTHOR(S): R. W. Warren

MASTER

SUBMITTED TO: Ettore Majorana Centre for Scientifc Culture

International School of Quantum Electronics

University of California

LOS ALAMOS SCIENTIFIC LABORATORY
Post Office Box 1663 Los Alamos, New Mexico 87545
An Affirmative Action/Equal Opportunity Employer

UNITED STATES
DEPARTMENT OF ENERGY
CONTRACT W-7405-ENG. 36

FEL DEVELOPMENT PROGRAM AT LOS ALAMOS SCIENTIFIC LABORATORY*

R. W. Warren, AT-1†

Los Alamos Scientific Laboratory
Los Alamos, New Mexico 87545

INTRODUCTION

The Los Alamos Scientific Laboratory (LASL) has embarked upon an ambitious FEL research program that will last several years, and includes at least three separate experiments. In this paper we shall briefly discuss the overall program, but shall emphasize the first "gain" experiment in which we are now involved in design and construction. We will cover mostly the practical features of the experiments and will point out the problem areas we have found.

LASL is especially well suited for FEL experiments because of its experience and expertise in both accelerator and laser technology. The accelerator expertise matured during the design and construction of LAMPF, the half-mile-long, 800-MeV proton accelerator used to produce mesons. The laser expertise developed to serve the needs of the large inertial-fusion program at LASL. This program uses many kinds of laser systems, but concentrates on the topics of most immediate importance to us; that is, 10.6-μm wavelength, good beam quality, high power, and short pulses. Many of the personnel involved in the FEL experiments were selected from the accelerator and laser programs and thus we have had good information exchange with them.

LASL's goal in the three-phase FEL program is to build an efficient, high-average power, 10.6-μm laser. Because it is difficult to achieve high efficiency with a single pass of an electron beam through a wiggler, either the same beam must be passed through the wiggler several times or the energy remaining after a single pass must be recovered in some way. Several passes from a single beam is difficult

*Work performed under the auspices of the U.S. Department of Energy with the support of the Air Force Office of Scientific Research, the Defense Advanced Research Projects Agency and the Naval Air Systems Command.

†Industrial Staff Member from Westinghouse Research Laboratory.

because of the accumulating degradation in the beam's quality. On the other hand, great ingenuity must be exercised to find a recovery technique with acceptable efficiency and cost.

RACETRACK EXPERIMENT

The technique that LASL will use to achieve high efficiency is based upon an electron accelerator that is divided into two sequential parts. The first section is conventional but the second serves two functions: it accelerates electrons on a first pass and decelerates them on a second pass to recover a part of their energy. Figure 1 shows this process in some detail. Starting at the injector, electrons are accelerated to 90 keV in the gun, then, after bunching, they are accelerated to 7 MeV in the first linac section. At this point they are inserted into the main loop, enter the second linac section, and gain an additional 13 MeV. After undergoing a 180° bend, they pass through the wiggler and transfer several percent of their energy to 10.6-μm light. Following another 180° bend, they re-enter the second linac, but this time the electron bunches enter with a different phase relative to the accelerating fields. The phase is right to decelerate the electrons and transfer their kinetic energy back into rf energy in the cavities of the accelerator. In this way, 13 MeV will be recovered from the beam. The remaining energy is lost in the beam dump. We expect this technique to increase the efficiency of operation by a factor of four. Even higher efficiencies are possible and may be attempted if time permits.

We know that the main features of this recovery technique work, but, clearly, many problems must be solved concerning the bending and

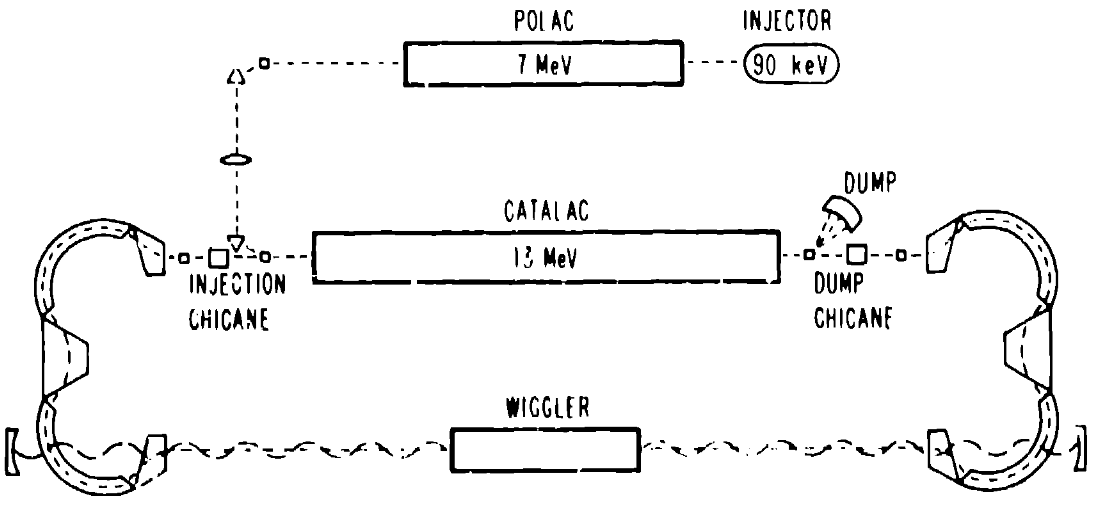

Fig. 1. Racetrack energy recovery system.

focusing of the electron beam and the overall stability of the system during the simultaneous acceleration and deceleration of the beams. For this part of the program, we expect to rely heavily upon the expertise of accelerator specialists.

OSCILLATOR EXPERIMENT

Moving back a step to the second "oscillator" experiment, we will depend very heavily upon the expertise of the laser specialists. In this experiment we will investigate the build-up of laser oscillations. The wiggler must perform adequately at all power levels from noise up to the gigawatt level. The accelerator must generate a train of micropulses whose length exceeds the build-up time of the laser oscillations. The optical beam quality must be well characterized and its dependance upon the various parameters of the electron beam and wiggler must be understood. The intricacies of optical pulse propagation in the electron beam-wiggler medium must be unraveled.

GAIN EXPERIMENT

Moving back another step, we come to the "gain" experiment on which we are now working. During this phase we will design and construct a system that can produce a significant optical gain and energy extraction efficiency when operating at very high optical power levels. The peak power in our optical beam is 1 GW; in our electron beam, 0.4 GW. These high power levels and the large ratio of optical to electron power put us into a different operating region from previous workers. Our main task is to design and to test the components, in particular the tapered wiggler, which make such operation possible. In the following pages, we will discuss these major components, emphasizing their design problems and the choices made to avoid or to deal with them. Figure 2 shows the general layout of the experiment.

Accelerator

A 5-MeV electron linac recently has been used in LASL experimental programs. This linac is being upgraded now to 20 MeV by adding cavity sections similar to those already in use. Table 1 shows specifications of the present and upgraded accelerator. The operating cycle of the linac will be as follows: the injector will be gated "on" every second or so to inject into the accelerator a pulse of electrons about 5 ns long. The accelerator, by its nature, will bunch this macropulse into a series of five or so 20-ps micropulses separated by about 1 ns and will accelerate them to 20 MeV. Gain and energy extraction can occur in the wiggler only when these micropulses overlap the laser beam both in space and time.

Of particular importance to the experiment are the current and the quality of the electron beam; for example, its spread in energy, space,

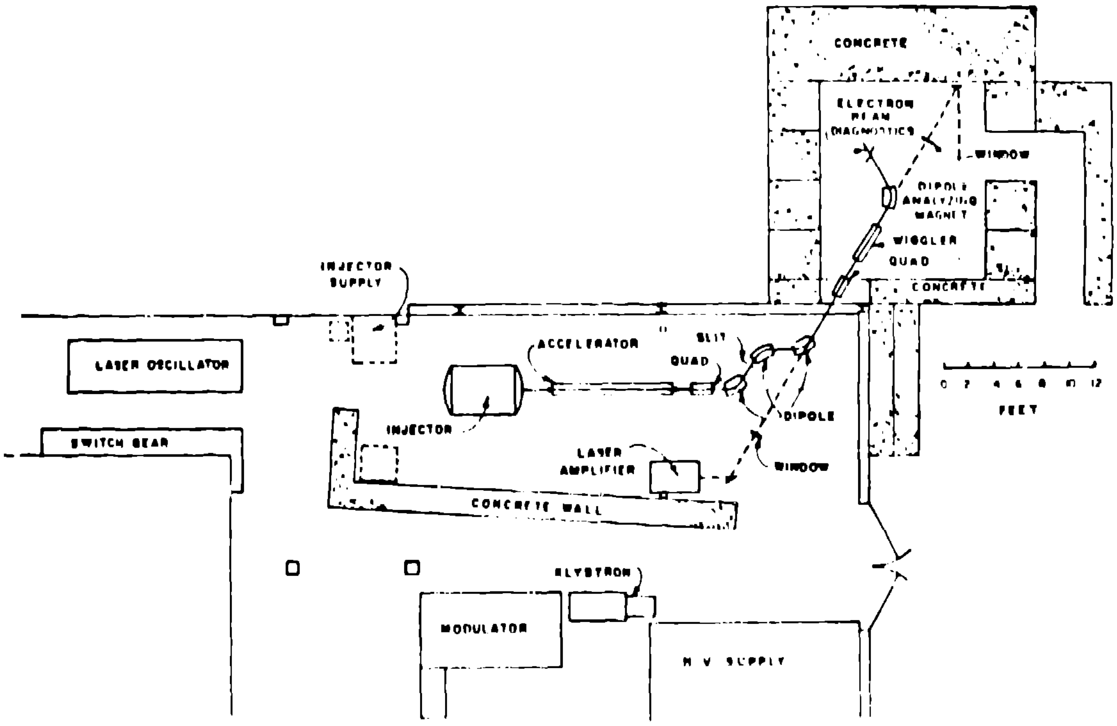

Fig. 2. Gain experiment.

and momentum. The energy spread can be reduced by better bunching and by reducing the loading of the accelerator cavities by the beam, but high beam currents and long macropulses worsen these effects. The spatial and momentum spread are associated mostly with the injector's gun. These values are adequate for the experiments at 10.6 μm, but operation at shorter wavelengths probably will require improvements.

Table 1. Specifications of present and upgraded accelerator.

	Present	Upgraded
Energy (MeV)	3-6	20
Frequency (GHz)	1.3	1.3
Peak μ-Pulse Current (A)	20	20
Operation	Steady State	Stored Energy
Energy Spread from Single-Bunch Beam Loading (%)	± 1	± 1
Energy Droop Per μ Pulse (%)	~ 0	0.1
Emittance at 20 A (mrad-mm)	~ 10π	~ 2π
Accelerator Length (m)	0.5	2.5
Pulse Length (ns)	300-1000	5

Figure 2 shows two major jogs in the electron beam line; their major purpose is to allow the joining of the electron and laser beams at the entrance to the wiggler and their subsequent separation at its exit. A secondary purpose of the second jog is to disperse the electron beam so that its energy-loss spectrum can be analyzed. The first complex jog includes three bends from three dipoles. The overall bend is doubly achromatic to maintain beam quality, but at the intermediate point in Fig. 2, where a slit is shown, the beam will be dispersed strongly. A system of slits and beam stops will be used there, to block the expected low-energy tail and to pass only a narrow distribution on to the wiggler.

Laser

In the gain experiment we wish to employ parameters that also are characteristic of the oscillator experiment. We therefore need a laser whose power ouput is as high as possible. Additionally, we need an optical beam of high quality, but only require a pulse length as long as the electron beam's macropulse, that is, 5 ns. Following these three major constraints, we have designed the CO_2 laser oscillator-amplifier combination, shown in Fig. 3. It will deliver a single longitudinal mode, 1-GW, 1-5 ns pulse of the P(20) line of CO_2 with good spatial and temporal quality.

In Fig. 3 five major elements can be noted: 1) the 2-m cavity oscillator containing both a high-pressure high-gain medium and a low-pressure low-gain smoothing tube, used to select a single mode for oscillation; 2) the electro-optical switch used to pass only a short part (1-5 ns) of the oscillator's output; 3) the four-pass intermediate amplifier, which uses the same gain medium as the oscillator; 4) the combination of spatial filter, isolator, and beam expander used to improve the beam's quality, protect the intermediate amplifier from reflected light, and prepare the beam for the final amplifier; and 5) the final amplifier, a commercially available three-pass Lumonics 600 amplifier.

From the final amplifier, the polarized light will be led to the wiggler by copper mirrors and a salt window. The sizes of the windows and mirrors and their spacings from the wiggler are determined by their damage thresholds.

The focal length of the final mirror is determined by the energy density desired at the focal spot and its depth of focus within the wiggler. These are chosen in a complex way to maximize the gain of the wiggler.

Wiggler

In designing the wiggler, we have deliberately sacrificed gain to enhance our diagnostic abilities and to achieve flexibility. In particular, we have provided room to monitor the position and shape of

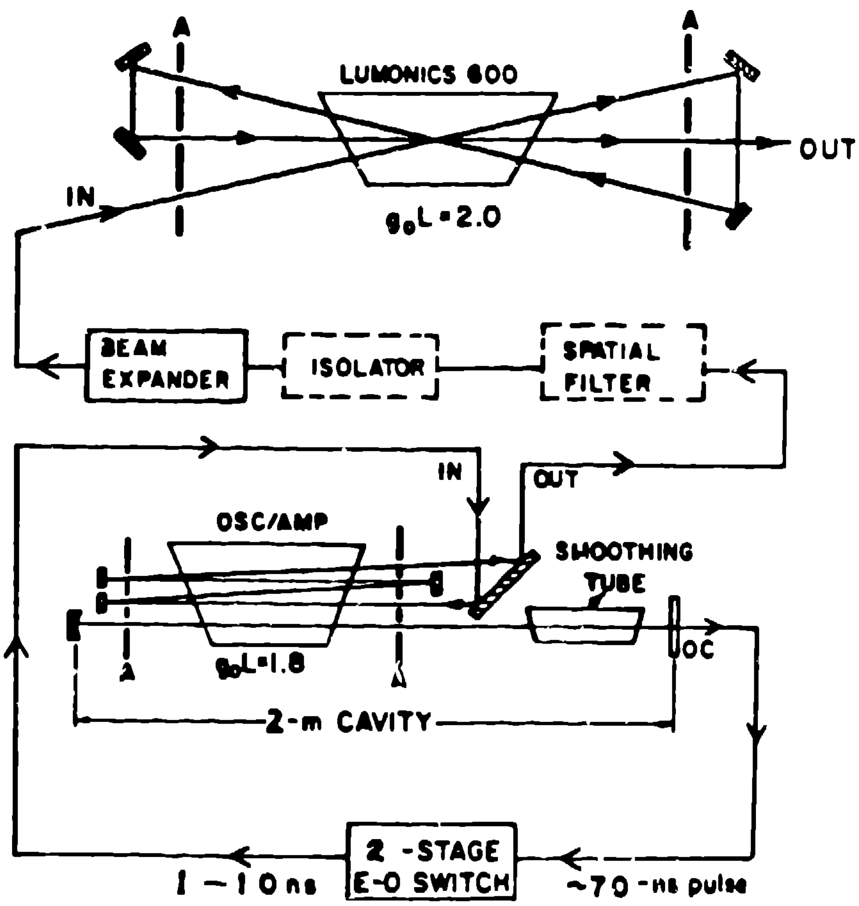

Fig. 3. The 10.6-μm laser system.

the electron beam inside the wiggler and anticipate altering the taper in magnetic field during the experiment. The use of hundreds of $SmCo_5$ permanent magnets of a fixed size but variable spacing facilitates such alterations. However, we are concerned that variations in magnet strengths will affect the field and bend the electron beam or deflect it away from the laser beam. Accordingly, we have designed a complex test program to evaluate each of the magnets used in the wiggler. From these tests we will select magnets so that adjacent ones cancel to a high degree the aberrations of their neighbors. Finally, we will test the completed wiggler by measuring the deflection of a fine current-carrying wire that will simulate the electron beam Residual field aberrations will be corrected by a series of 20 "trim" coils mounted outside the wiggler.

To achieve as high a field as possible, the magnets are placed in the vacuum chamber very near the electron and laser beams. Vacuum properties of sintered $SmCo_5$ have been questioned, but preliminary tests show no need for concern. Because of the brittle nature of the magnets and because of their presence in the vacuum system, a mounting technique was needed that avoided complex machining operations or complicated hardware. The technique chosen depends upon two perpendicular grooves cut in each end of the bar magnets. It includes long metal bars machined with regularly spaced teeth that mesh with one groove at each end of each magnet. The spacing between magnets can be changed by inserting a new bar with a different tooth spacing. There are two grooves at each end to allow the square cross-section magnets to be held with any orientation differing by 90°. Special entrance and exit regions are provided at each end of the wiggler to allow the electron beam to enter and to leave the wiggler with no unbalanced deflections at the transitions.

Diagnostics

There are three measurements that are especially important to the experiment's success: one to assure that the electron and laser beams overlap in the wiggler, one to determine the average energy extracted from the electron beam and the spectrum of the depleted electrons, and one to measure the optical gain and the quality of the generated light.

Overlap of the beams will be assured with a system of apertures, fluorescent screens, and an auxiliary He-Ne laser. First, two small apertures are placed at the entrance and exit of the wiggler, and the He-Ne laser is adjusted until a maximum of its light penetrates the wiggler and both apertures. Next, two larger apertures are inserted and the same maximizing adjustment is made with the CO_2 laser. Finally, the electron beam is turned on and a fluorescent screen is inserted into its path while the He-Ne laser is operating. Two spots will be seen on the screen: the fluorescent spot from the electron beam and the scattered-light spot from the He-Ne laser. If the electron beam is moved to superimpose the spots, it will be correctly aligned with the CO_2 laser. In this way the electron beam can be aligned at the three screens provided; that is, at the entrance, exit, and midpoint of the wiggler. We will adjust the beam position with the 20 trim coils wound around the wiggler and by other steering coils located further up the beam line.

The average energy and the spectrum of the depleted electrons will be determined after they have been bent and dispersed by the final magnet. The beam will strike a fluorescent screen and will be viewed by a vidicon. The calculated energy spread is large enough to be resolved easily.

We expect the measurement of optical gain and beam quality to be difficult because the gain is small (2%) and it occurs only during the electron beam's micropulse, that is, only about 2% of the time that the laser is operating. The gain measurement would be easier if it could be performed only during a micropulse, but it is difficult to resolve the gain's temporal variations with existing instruments. If no attempt is made to resolve them, but an average gain is measured, it will be only about 10^{-3}. It at first appears attractive to use some technique to subtract the input laser pulse from the output light so as to detect only the gain contribution. Various schemes have been suggested using polarizers or narrow-band absorption cells, but they all suffer from two serious problems: low signal level, and an indirect connection between the detected signal and the desired gain. We intend to install a very flexible optical measurement system that will allow us to test several different gain-measuring techniques and to perform other measurements on the output beam quality. The details of this system are still being worked out.

ACKNOWLEDGMENT

The work discussed above was performed by a team composed of B. Newnam, W. Stein, L. Young, and the author under the direction of C. A. Brau. The author is grateful for their help in preparing this paper.